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COVARIATION AMONG MEASURES OF COGNITIVE ABILITY AND ACADEMIC ACHIEVEMENT IN THE COLORADO ADOPTION PROJECT: SIBLING ANALYSIS

S. J. Wadsworth,[1] J. C. DeFries[1] D. W. Fulker[1] and R. Plomin[2]

[1]Institute for Behavioral Genetics, University of Colorado, Boulder, CO 80309, U.S.A. and [2]Center for Developmental and Health Genetics, Pennsylvania State University, U.S.A.

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Summary—Although correlations among measures of cognitive ability and academic achievement are substantial, relatively little is known about the etiology of their interrelationships. The purpose of the current study was to assess the etiology of these relationships by applying the methods of multivariate behavioral genetic analysis to sibling data from the Colorado Adoption Project.

The current study analyzed data from 100 pairs of related siblings and 90 pairs of unrelated siblings tested at age 7 on two measures of cognitive ability (verbal comprehension and perceptual organization) and two measures of academic achievement (reading recognition and mathematics achievement). Phenotypic correlations among the cognitive and achievement measures averaged about 0.30. Although a substantial proportion of the covariation among the measures was due to influences shared with verbal ability, results of fitting a Cholesky factor model to the data provided evidence for significant covariation between the achievement measures that was independent of cognitive ability.

Results of the genetic analysis confirmed previous findings of substantial genetic influence, with heritabilities ranging from 0.21 for mathematics achievement to 0.60 for perceptual organization. The environmental variance was primarily due to nonshared influences specific to each of the measures, with shared environmental influences being nonsignificant. In addition, genetic influences accounted for most of the phenotypic covariance among the variables, with much of the genetic covariation being due to influences shared with verbal ability.

INTRODUCTION

Measures of scholastic achievement are substantially correlated with IQ, and recent twin and adoption studies suggest that this correlation may be largely due to genetic influences. Because measures of both IQ and achievement are moderately heritable (Loehlin & Nichols, 1976; Plomin & DeFries, 1979; Cherny & Cardon, 1994; McGue, Bouchard, Iacono & Lykken, 1993; Wadsworth, 1994), genetic factors which influence general cognitive ability may also affect scholastic achievement. Alternatively, because educational systems attempt to foster both ability and achievement, associations between IQ and achievement measures may be mediated environmentally (Cardon, DiLalla, Plomin, DeFries & Fulker, 1990). The first multivariate twin analysis to assess the etiology of the correlation between IQ and achievement supported the genetic hypothesis (Brooks, Fulker & DeFries, 1990). In a study of 86 monozygotic (MZ) and 60 dizygotic (DZ) twin pairs participating in the Colorado Reading Project, genetic factors were found to account for most of the observed covariation between full-scale IQ and reading achievement.

Two other twin studies yielded highly similar results. Thompson, Detterman and Plomin (1991) examined scores of 146 MZ and 132 DZ twin pairs on measures of specific cognitive abilities (verbal, spatial, perceptual speed and memory) as well as on measures of reading, mathematics and language skills. All measures of specific cognitive abilities evidenced moderate to high heritabilities, with estimates ranging from 0.37 for memory to 0.74 for spatial ability. The achievement measures were less heritable, with heritabilities of 0.27 for reading, 0.17 for math and 0.19 for language, while shared environmental influences accounted for 65–73% of the variance in these measures. Nevertheless, genetic correlations were high, averaging 0.79 between measures of spatial ability and scholastic achievement, and 0.85 between measures of verbal ability and scholastic achievement. The authors concluded that the phenotypic correlations among these measures were almost entirely due to shared genetic influences.

More recently, Gillis (1993) assessed the etiology of the interrelationships between verbal comprehension, phonological coding and reading and mathematics achievement. Results of

Table 1. Sample sizes

Type of individual	Number of *S*s
Probands	
Adopted probands (A_1)	198
Nonadopted control probands (C_1)	215
Siblings	
Adopted siblings of adoptees (A_2)	66
Nonadopted siblings of adoptees (S_2)	24
Full siblings of nonadoptees (C_2)	100

Table 2. Sample sizes for each of the measures included in the full sibling model

Individual type	VERB	PERCEP	REC	MATH
Adopted probands	197	198	195	195
Unrelated siblings	90	90	90	90
Control probands	215	215	211	211
Related siblings	100	98	100	99

multivariate analyses of 134 MZ and 93 DZ twin pairs participating in the Colorado Reading Project indicated that over half of the observed covariation between measures of cognitive ability and academic achievement are due to genetic influences.

In addition to these findings from twin studies, similar results were obtained in a parent–offspring adoption analysis of data from the Colorado Adoption Project (Cardon *et al.*, 1990). Parent–offspring data from a sample of 119 adoptive and 120 nonadoptive families were used to assess the relationships between reading recognition and Full-Scale, Verbal and Performance IQ. All measures were moderately heritable, and genetic influences accounted for 67–78% of the phenotypic correlations.

The purpose of the present study is to test the hypothesis of substantial genetic mediation of the relationship between cognitive ability and academic achievement using the sibling adoption design from the Colorado Adoption Project (CAP). The sibling adoption design compares the resemblance between nonadoptive siblings (biologically related siblings in nonadoptive families) and adoptive siblings (genetically unrelated children in the same adoptive family). Based on the results of the three previous twin studies and the parent–offspring adoption analyses, we predicted that the correlations between measures of cognitive ability and academic achievement are largely due to common genetic influences.

METHODS

Subjects

The subjects are participants in the Colorado Adoption Project (CAP), an ongoing longitudinal study of genetic and environmental influences on behavioral development. Adoptive families were recruited through two adoption agencies in Denver, CO. Data from a wide variety of measures were collected from both adoptive and biological parents, and are currently being obtained from adopted children and their unrelated siblings. All adopted children were separated from their biological parents within a few days of birth and placed in adoptive homes within one month. The CAP sample consists of 245 adoptive families (including 116 unrelated sibling pairs) and 245 nonadoptive control families (including 122 related sibling pairs) which are matched to the adoptive families according to age, education and occupational status of the fathers, gender of the adopted child, and number of children in the family. Detailed descriptions of the CAP design and sample have been provided by Plomin & DeFries (1985), Plomin, DeFries & Fulker (1988), and DeFries, Plomin & Fulker (1994).

For the present study, cognitive ability and achievement data from 90 pairs of adopted children and their unrelated siblings, as well as from 100 pairs of nonadopted control children and their related siblings, were collected during the summer following first grade (average age of 7.4 years). Unrelated siblings of adoptees may be either adopted or nonadopted. Sample sizes are given in Table 1. However, not all data are available for all subjects; therefore, numbers of individuals for which data are available for each measure are provided in Table 2.

Measures

The current study examined scores of probands and siblings on the Reading Recognition (REC) subtest of the Peabody Individual Achievement Test (PIAT) (Dunn & Markwardt, 1970), as well as the Kaufman (1975) Verbal Comprehension (VERB) and Perceptual Organization (PERCEP) factors of the Wechsler Intelligence Scale for Children-Revised (WISC-R) (Wechsler, 1974) or the Wechsler Adult Intelligence Scale-Revised (WAIS-R) (Wechsler, 1981). A composite measure of mathematics achievement (MATH) based on the Numeration, Addition, and Subtraction subtests of the KeyMath Diagnostic Arithmetic Test (Connolly, Nachtman & Pritchett, 1976), and the Arithmetic subtest of the WISC-R was also analyzed.

Analyses

Phenotypic analysis. The current study employed the Cholesky decomposition (Neale & Cardon, 1992) to examine the phenotypic factor structure among the variables. Figure 1 depicts the phenotypic model which was fitted to the data by the method of maximum likelihood estimation using the MX statistical modeling package (Neale, 1991). The use of the Cholesky facilitates exploration of the factor structure among the variables, permitting a more thorough interpretation of their interrelationships. For example, using this model, we can determine the extent to which the correlation between the achievement measures is due to influences shared with verbal ability, i.e. $\lambda_{31} \times \lambda_{41}/r_{P_{REC.MATH}}$, where $r_{P_{REC.MATH}} = (\lambda_{31} \times \lambda_{41}) + (\lambda_{32} \times \lambda_{42}) + (\lambda_{33} \times \lambda_{43})$.

Because of the variability in patterns of missing data in the CAP (Table 1), a maximum likelihood pedigree approach was employed in order to make use of all available data, thereby increasing both power to detect effects and precision of parameter estimates. The pedigree approach involves the calculation of a log-likelihood for each family, and the summation of these across all pedigrees. The following log-likelihood function is minimized:

$$L_i = -\tfrac{1}{2}\ln|\Sigma_i| - \tfrac{1}{2}(x_i - \mu)'\Sigma_i^{-1}(x_i - \mu) \tag{1}$$

where, for the i^{th} pedigree, Σ_i represents the matrix of expected covariances among scores of family members, x is a variable length vector of observed family data, and μ is a vector of expected means. The appropriate mean vector μ and covariance matrix Σ are automatically created by MX for each observation (Neale, 1991). For model comparisons, twice the difference between the log-likelihoods for the two models is distributed asymptotically as a chi-square, with degrees of freedom equal to the difference in the number of free parameters estimated in fitting each model.

Genetic analysis. The basis of the adoptive sibling design lies in the comparison of the correlations of unrelated siblings to those of related siblings (Plomin, *et al.*, 1988; Falconer, 1989). While adoptive siblings are genetically unrelated, and share only family environmental influences, related siblings share, on average, half of their segregating genes. Therefore, in the absence of genetic nonadditivity, the phenotypic correlation between related siblings is a function of one-half the heritability of the trait, plus shared environmental influences (e.g. home environmental influences shared by the siblings, which are assumed to be no more highly correlated for related siblings than for unrelated siblings). In contrast, the phenotypic correlation between genetically unrelated adoptive siblings arises only from shared environmental influences (in the absence of selective placement). By analyzing these correlations, the contributions of genetic, shared environmental, and nonshared environmental influences (i.e. those environmental influences which contribute to differences between the members of a sib pair) can be estimated. Figure 2 illustrates the application of structural equation modeling to data from related and unrelated siblings. This is a simplified univariate example of the model used in the present study, representing the effects of additive genetic (A), shared environmental (C), and nonshared environmental (E) influences on the phenotype (P) of each sibling. Heritability is estimated as the square of the genetic path (a), while shared and nonshared environmentalities are estimated as the square of the shared environmental (c) and nonshared environmental (e) paths, respectively.

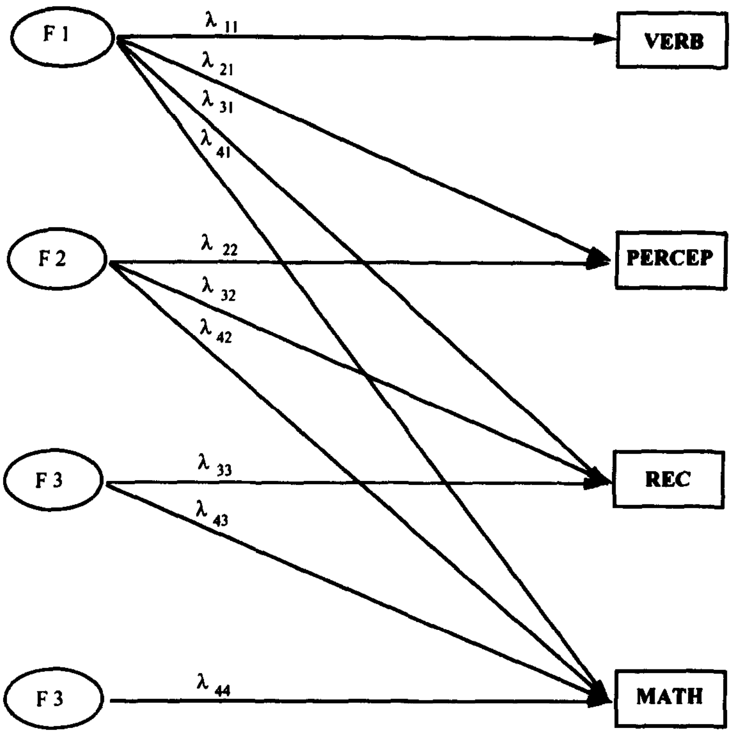

Fig. 1. Cholesky model of phenotypic factor structure among measures of verbal comprehension (VERB), perceptual organization (PERCEP), reading (REC) and mathematics (MATH) performance.

The genetic correlation between related siblings for the same trait is 0.5 (assuming additivity of genetic effects), whereas that for adoptive siblings is 0.0 (because they are not genetically related). The shared environmental correlation is 1.0 for both related and unrelated siblings because shared environmental influences are assumed to be equal for related and unrelated sibling pairs. This model is just-identified, since for any given measure there are two correlations (a related sibling correlation and an unrelated sibling correlation) from which to derive h and c, with e as a residual.

For the genetic analyses, the phenotypic model was partitioned to include genetic, shared environmental, and nonshared environmental contributions to the variance in each of the measures, as well as to the correlations between the measures. Figure 3 depicts the model, illustrating the genetic and environmental factor structures underlying measures of VERB, PERCEP, REC and MATH for one sibling only. Using this model, the etiology of the relationships among the measures of cognitive ability and achievement can be assessed, and the extent to which the correlation between the achievement variables is due to genetic and environmental influences shared with the cognitive ability factors can be quantified. In this manner, the model can provide evidence for common or independent genetic and environmental influences on the various measures. In addition, estimates of heritability, environmentality, and genetic and environmental correlations among the measures are computed with relative ease.

Proportions of variance for each of the measures due to genetic and environmental effects are calculated from the standardized path coefficients as the sum of the squared paths from common and specific factors to each measure. For example, from Fig. 3, the heritability of VERB is simply the square of the path from A_{VERB} to VERB, i.e. a^2_{11}, whereas that for PERCEP equals $a^2_{21} + a^2_{22}$, etc. An analogous procedure is used to obtain estimates of shared (c^2) and nonshared (e^2) environmental influences.

Estimates of the genetic, shared environmental and nonshared environmental correlations among the measures are also obtained from the standardized path coefficients. For example, $a_{11} \times a_{21} = a_{VERB} \times r_A \times a_{PERCEP}$, the phenotypically standardized genetic correlation, where a equals the square root of the heritability of the measure, and r_A equals the genetic correlation between the two measures. Thus, the genetic correlation is calculated as the ratio of the phenotypically standardized genetic correlation to the product of the square roots of the two heritabilities (i.e. $r_A = a_{VERB} \times r_A \times a_{PERCEP}/a_{VERB} \times a_{PERCEP}$). That portion of the phenotypic correlation which is due to shared genetic

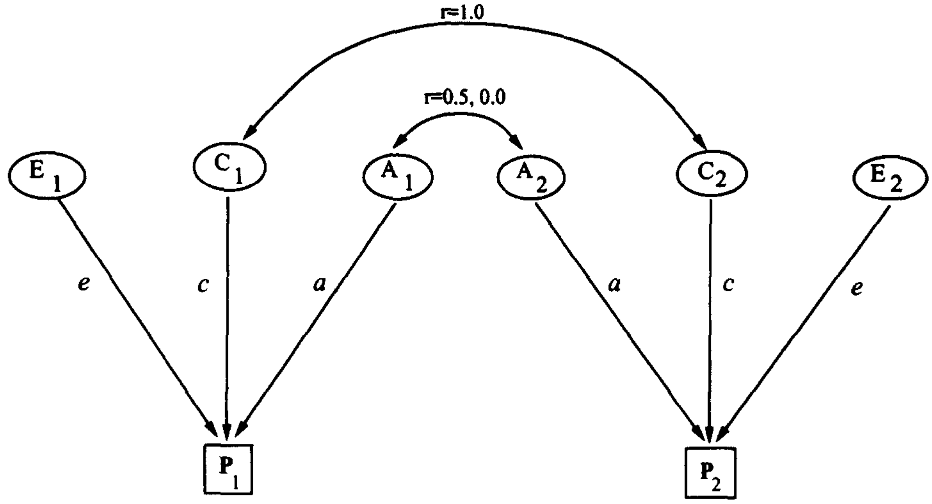

Fig. 2. Path diagram of sibling resemblance.

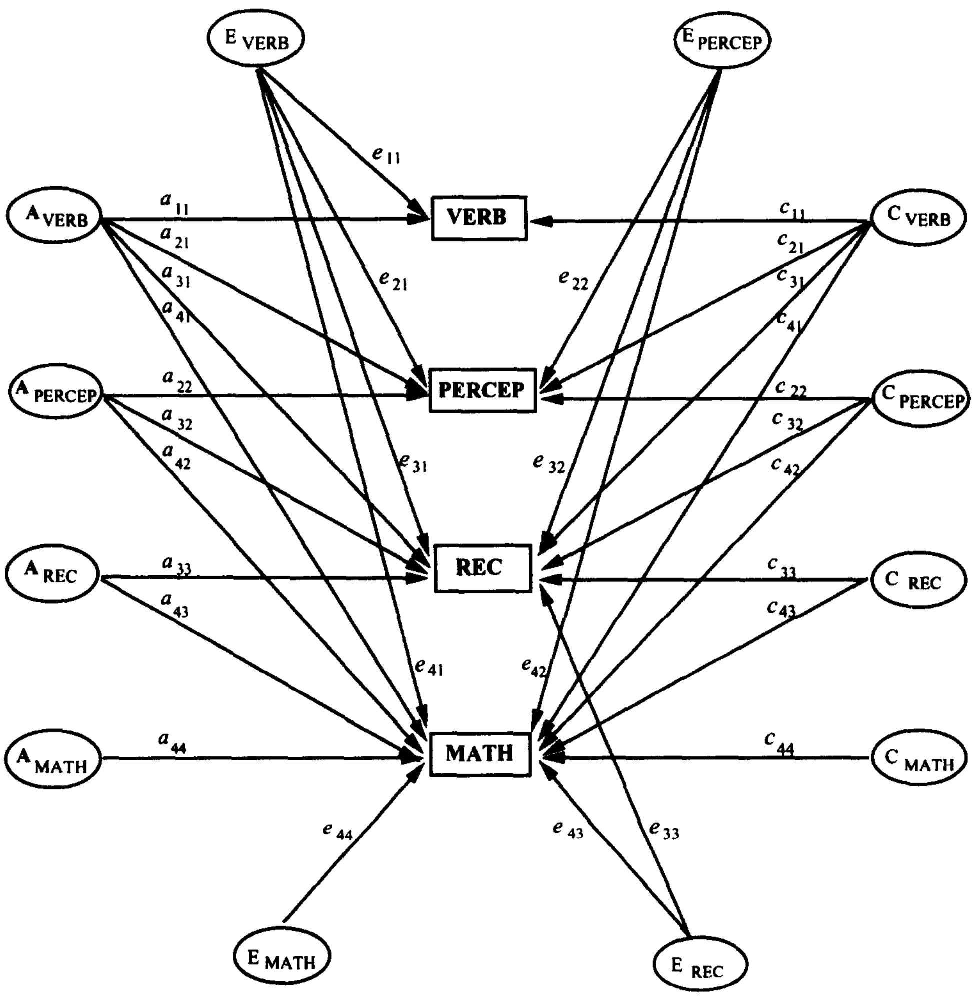

Fig. 3. Partitioning of the phenotypic Cholesky into genetic, shared environmental, and nonshared environmental factors.

Table 3. Phenotypic correlations among measures of cognitive ability and academic achievement

	VERB	PERCEP	REC	MATH
VERB	1.00			
PERCEP	0.32	1.00		
REC	0.36	0.18	1.00	
MATH	0.40	0.28	0.40	1.00

influences is obtained from $a_{11} \times a_{21}/r_p$, where r_p represents the phenotypic correlation between the measures.

RESULTS

Phenotypic analyses

Phenotypic correlations among measures of cognitive ability and academic achievement at age 7 are presented in Table 3, ranging from 0.18 for the observed correlation between REC and PERCEP to 0.40 for both VERB and MATH and REC and MATH. It is interesting to note that the correlation between VERB and MATH is slightly higher than that between VERB and REC.

Application of the full phenotypic Cholesky to the year 7 sibling data yielded a log-likelihood of -3117.49 for the 10 parameters estimated. Results of fitting this model are presented in Fig. 4. Although correlations among the variables are moderate, a large proportion of the variance is specific to each measure. With respect to the relationship between the achievement variables, approx. 40% of the observed correlation between REC and MATH is due to influences shared with cognitive ability $[(0.36 \times 0.40 + 0.07 \times 0.16)/0.40]$, with most of this being due to the influence of VERB. However, 60% of the covariation between the achievement variables in this sample is independent of cognitive ability $[(0.93 \times 0.26)/0.40]$, with PERCEP contributing very little to their observed covariation. As noted previously, the relationship between VERB and MATH is slightly higher than that between VERB and REC. However, no single factor appears sufficient to account for the interrelationships among the measures, and model comparisons indicate that none of the factors can be excluded from the model without significant deterioration of model fit (Table 4).

Genetic analysis

For the genetic analysis, the phenotypic model was partitioned to include additive genetic, shared environmental and nonshared environmental contributions to the variance in each of the measures, as well as to the covariance among the measures. Sibling correlations among the measures of cognitive ability and academic achievement are presented in Table 5.

Application of the model to the year 7 data yielded a log-likelihood of -3096.34 for the 30 estimated parameters. The additive genetic, shared environmental, and nonshared environmental factor structures based on the full sibling model are presented in Fig. 5. Results of this analysis reveal substantial contribution of genetic influences to the variance in each of the measures, as well as to the covariance among the measures. In addition, the genetic relationships among the measures closely resemble the phenotypic results, with the genetic covariances being largely due to influences shared with VERB. In fact, 54% of the genetic covariance between the achievement measures is due to such influences $[(0.44 \times 0.26)/(0.44 \times 0.26 + 0.26 \times 0.10 + 0.19 \times 0.37)]$, with PERCEP contributing very little to their genetic variance or covariance. However, although the phenotypic relationship between VERB and MATH was similar to that between VERB and REC, the genetic relationship is somewhat greater between VERB and REC. In addition, one-third of the genetic covariance between the achievement measures is independent of cognitive ability $[(0.19 \times 0.37)/(0.44 \times 0.26 + 0.26 \times 0.10 + 0.19 \times 0.37)]$ Thus, although much of the genetic covariation among the measures is due to influences shared with VERB, there is substantial genetic variation independent of verbal ability.

Shared environmental influences are relatively weak. However, similar to the phenotypic results, the shared environmental path between VERB and MATH is highly similar to that between VERB

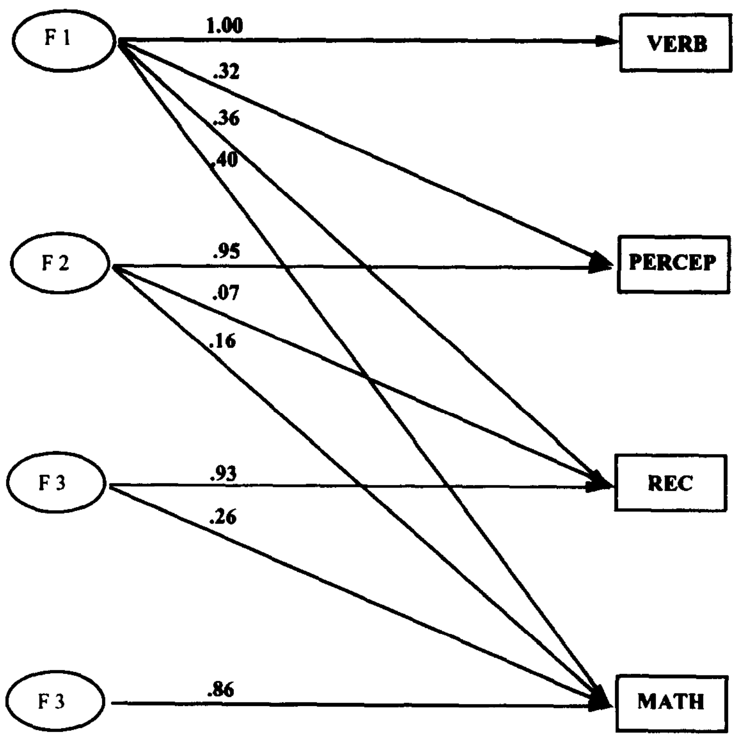

Fig. 4. Observed phenotypic factor structure among measures of cognitive ability and academic achievement at age 7.

Table 4. Model comparisons for phenotypic Cholesky based on year 7 data

Model	Log-likelihood	NPAR	vs.	χ^2	*df*	$P \leq$
1. Full	− 3117.79	10				
2. 1 Factor + specifics	− 3154.05	7	1	72.52	3	0.001
3. VERB and REC factors + specifics	− 3127.14	8	1	18.70	2	0.001
4. VERB and PERCEP factors + specifics	− 3143.28	9	1	50.98	1	0.001

and REC. There is, however, very little shared environmental covariation between REC and MATH independent of cognitive ability. As expected, nonshared environmental influences are primarily specific to the individual measures.

Estimates of genetic and environmental contributions to the variance in each of the measures confirms substantial genetic influences on individual differences in performance on all measures, with heritability estimates ranging from 0.21 for MATH to 0.60 for PERCEP (Table 6). Nonshared environmental influences are important for all of the measures, but less so for PERCEP, which has a heritability twice that of any other measure. In contrast, shared environmental contributions are negligible for the ability measures, but somewhat larger for the achievement measures.

Estimates of the genetic and environmental correlations are presented in Table 7, with the

Table 5. Sibling correlations for measures of cognitive ability and academic achievement

	PROBAND							
	Unrelated				Related			
	VERB	PERCEP	REC	MATH	VERB	PERCEP	REC	MATH
Sibling								
VERB	0.07	0.13	0.13	0.20	0.21	0.01	0.24	0.10
PERCEP	− 0.10	− 0.01	− 0.14	− 0.04	0.11	0.34	0.05	− 0.07
REC	0.12	0.02	0.06	0.05	0.18	0.10	0.28	0.11
MATH	0.05	− 0.03	0.08	0.22	0.21	0.13	0.31	0.31

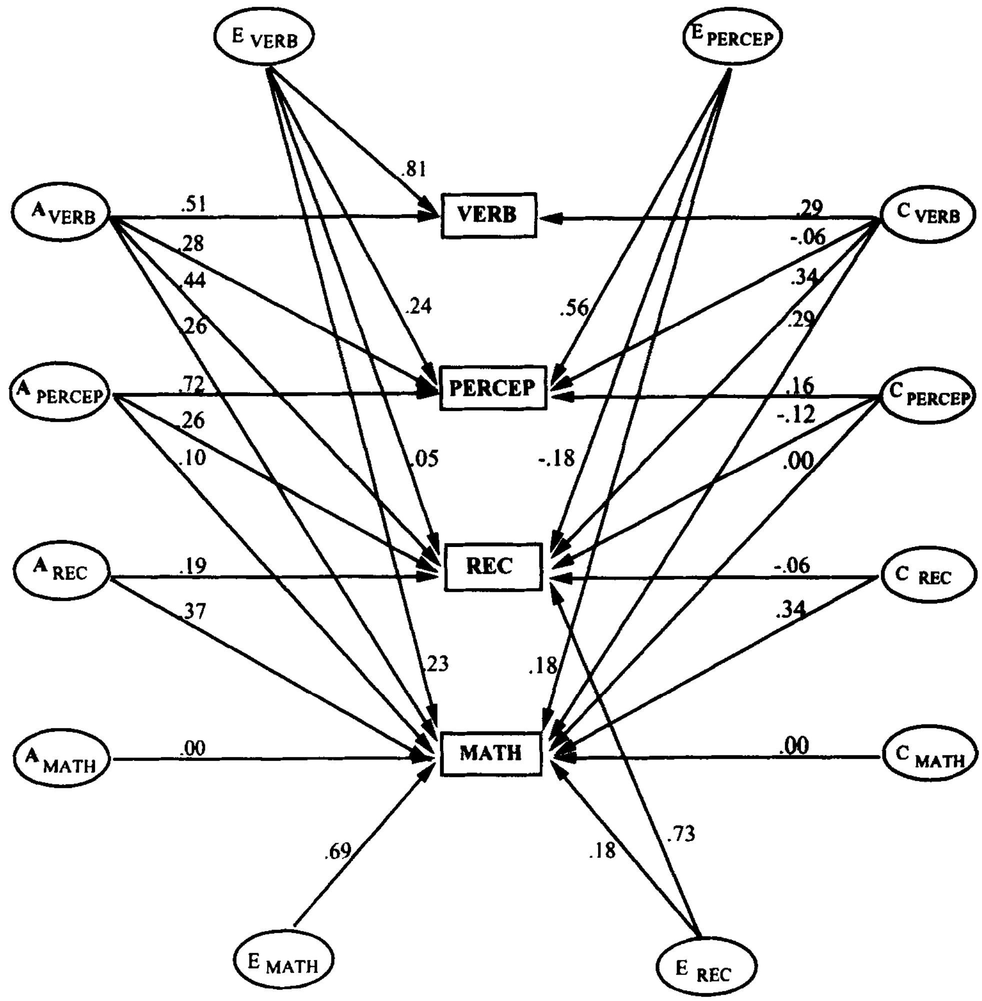

Fig. 5. Genetic and environmental factor structures among measures of cognitive ability and academic achievement based on analysis of year 7 sibling data.

phenotypically standardized genetic ($a_x \times r_{A_{x,y}} \times a_y$), shared environmental ($c_x \times r_{C_{x,y}} \times c_y$), and nonshared environmental ($e_x \times r_{E_{x,y}} \times e_y$) correlations above the diagonal. Genetic correlations are substantial, ranging from 0.36 between VERB and PERCEP to 0.83 between REC and MATH. The phenotypically standardized genetic correlation of 0.22 between VERB and REC accounts for approx. 60% of their observed covariation ($a_{VERB} \times r_{A_{VERB,REC}} \times a_{REC}/r_{P_{VERB,REC}}$), and that of 0.13 between VERB and MATH accounts for one-third of their phenotypic relationship. The phenotypically standardized genetic correlation of 0.15 between PERCEP and MATH, and that of 0.21 between REC and MATH, account for approximately half of the phenotypic covariation among these measures. Although some of the shared environmental correlations appear to be substantial, shared

Table 6. Genetic and environmental contributions to the variance in each of the measures estimated from the full sibling model

Measure	a^2	c^2	e^2
VERB	0.26	0.08	0.66
PERCEP	0.60	0.03	0.37
REC	0.30	0.13	0.57
MATH	0.21	0.20	0.59

Table 7. Genetic and environmental correlations estimated from the full sibling model, with phenotypically standardized genetic and environmental correlations above the diagonal

	VERB	PERCEP	REC	MATH
Genetic				
VERB	**1.00**	0.14	0.22	0.13
PERCEP	0.36	**1.00**	0.31	0.15
REC	0.80	0.72	**1.00**	0.21
MATH	0.57	0.41	0.83	**1.00**
Shared environmental				
VERB	**1.00**	−0.02	0.10	0.08
PERCEP	−0.37	**1.00**	−0.04	−0.02
REC	0.95	−0.65	**1.00**	0.08
MATH	0.67	−0.28	0.49	**1.00**
Nonshared environmental				
VERB	**1.00**	0.19	0.04	0.19
PERCEP	0.39	**1.00**	−0.09	0.16
REC	0.07	−0.19	**1.00**	0.11
MATH	0.32	0.33	0.19	**1.00**

Table 8. Model comparisons for genetic/environmental Cholesky based on year 7 sibling data

Model	Log-likelihood	NPAR	vs	χ^2	*df*	*P*
1. Full	−3096.34	30				
2. No E common factors	−3099.17	24	1	5.66	6	$\geqslant 0.3$
3. No C	−3103.37	14	2	8.4	10	$\geqslant 0.5$
4. No A	−3157.12	14	2	115.90	10	$\leqslant 0.001$

environmental influences account for no more than 20% of the observed covariation among the measures.

Model comparisons were conducted to determine the most parsimonious model to fit the data (Table 8). To test the hypothesis that nonshared environmental influences are specific to each of the measures (i.e. do not contribute to covariation among the measures) all nonshared environmental common factors were dropped, leaving only the nonshared environmental specifics (Model 2). As can be seen from Table 8, these common factors could be dropped without significant deterioration of model fit. Because of the small contribution of shared environmental influences to the variance and covariance of the measures, it was hypothesized and confirmed that the entire shared environmental matrix could be dropped without significant loss of fit (Model 3). However, an attempt to drop all genetic influences from the model resulted in a highly significant reduction in model fit (Model 4).

Therefore, results of these analyses suggest that genetic influences on individual differences in performance on the measures of cognitive ability and academic achievement used in this study are moderate to strong. With the exception of MATH, for which genetic and shared environmental influences were approximately equal, there is little influence of shared environment on the measures. In addition, the phenotypic covariance among the measures is primarily due to shared genetic influences. Furthermore, nonshared environmental influences contribute significantly to the variance of the measures, but do not contribute to the observed covariances among them, and shared environmental influences do not contribute significantly to either the variances or covariances of the measures.

DISCUSSION

The purpose of the present study was to assess the etiology of the relationships among measures of cognitive ability and academic achievement by applying the methods of multivariate behavioral genetic analysis to sibling data from the Colorado Adoption Project. Results of the current study confirm previous findings of moderate phenotypic correlations among measures of cognitive ability and academic achievement. In addition, the highest correlations were between VERB and the other measures, with the correlation between VERB and MATH being highly similar to that between VERB and REC—a finding that is consistent with that of Gillis (1993). This may be due to the verbal nature of the mathematics tests used in these two studies. Comprehension of verbal instructions is necessary for tests of both cognitive ability and academic achievement, and the math measures used in these studies, like many tests of mathematics performance, rely heavily on verbal skills. Therefore, the correlation between verbal ability and mathematics performance may be a function of test design and administration.

When the data were subjected to Cholesky factorization, nearly 40% of the covariance between REC and MATH was due to influences shared with VERB. This result was not due to the order of entry of the cognitive ability measures in the factor analysis. When PERCEP was entered first, VERB continued to mediate a larger proportion of this covariance. In both cases there was substantial variance specific to each measure. Moreover, there was significant covariation between the achievement measures independent of cognitive ability—a finding that is consistent with results of previous studies (Brooks *et al.*, 1990; Gillis, 1993).

Results of the genetic analysis indicated that individual differences in performance on each of the measures were due substantially to genetic influences, with heritabilities ranging from 0.21 for MATH to 0.60 for PERCEP. The environmental variance was primarily due to nonshared influences, with shared environmental influences being negligible for the ability measures, and accounting for no more than 20% of the variance in the achievement measures. Furthermore, model comparisons indicated that shared environmental influences were nonsignificant. Although the estimates of genetic and environmental influences are in the same range as those obtained by other studies (Brooks *et al.*, 1990; Cardon *et al.*, 1990, Thompson *et al.*, 1991; Gillis, 1993), the individual estimates vary considerably among studies. Such variation may be due to differences in the ages of the subjects, the measures used, sample size and/or sample composition (twins/siblings vs parent–offspring, etc.).

Consistent with earlier studies, the covariances among the measures were primarily due to genetic influences. In addition, genetic covariances were largely due to influences shared with VERB. It is interesting to note that while the phenotypic relationship between VERB and MATH was highly similar to that between VERB and REC, the genetic relationship was found to be somewhat stronger between VERB and REC, whereas the nonshared environmental relationship was stronger for VERB and MATH.

In summary, results of the present study provide evidence for a substantial contribution of genetic influences to the variance in measures of cognitive ability and academic achievement, as well as to their covariance. However, the strongest relationships, both phenotypically and genetically, occurred between verbal ability and the achievement measures. In addition, nonshared environmental influences were specific to each of the measures, and shared environmental influences contributed little to either the variance or covariance of the measures.

What are the implications of these findings for understanding and enhancing student achievement? Although measures of IQ and academic achievement are moderately correlated, most of the variance in measures of academic achievement is independent of IQ. If genetic factors are primarily responsible for the covariation between IQ and academic achievement, then perhaps environmental intervention would be most effective if focused on those aspects of achievement which are uncorrelated with IQ. However, identifying such components of achievement may not be easy. Even characteristics such as motivation and perseverance may be causally related to intellectual performance. Because the interrelationships among measures of IQ and achievement have only begun to be elucidated, further investigation of these relationships, as well as the effects of other intervening variables, is clearly warranted.

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